Wetlands Ecol Manage (2022) 30:607–622
https://doi.org/10.1007/s11273-022-09887-z

EDITORIAL

Wetlands in drylands: diverse perspectives for dynamic landscapes

Suzanne Grenfell · Michael Grenfell · Stephen Tooth · Adriana Mehl · Emily O'Gorman · Tim Ralph · William Ellery

Received: 16 June 2022 / Accepted: 18 June 2022 / Published online: 6 August 2022

Keywords Hydrogeomorphology · Biogeochemistry · Climatic variability · Environmental change · Ecosystem services

Introduction

The United Nations Environment Programme (UNEP 1997) classifies global drylands according to an Aridity Index (AI), defined as the ratio between mean annual precipitation (MAP) and potential evapotranspiration (PET). Drylands are areas where AI is <0.65, collectively incorporating subhumid, semiarid, arid and hyperarid settings (UNEP 1997; see Fig. 1). Wetlands in drylands (hereafter WiDs) have distinctive hydrogeomorphological, biogeochemical, ecological, and social-ecological features, and as a result, they require carefully tailored research and management strategies.

The surface or near-surface expression of water in these otherwise dry and climatically-variable environments (e.g., Scoones 1991; Silvius et al. 2000) means that WiDs are considered to be hotspots of ecosystem service delivery (Tooth et al. 2015a), including provisioning services (e.g., foods, medicinal plants, building materials), regulating services (e.g., retention of soil and sediment, flood attenuation, carbon storage), supporting services (e.g., nutrient cycling, removal of toxicants) and cultural services (e.g., ecotourism, religious values). The dependence of many dryland societies on wetlands frequently results in a tension between human needs and the biophysical processes

S. Grenfell (✉)
Department of Geography and Environmental Studies, University of Stellenbosch, Stellenbosch 7602, South Africa
e-mail: sgrenfell@sun.ac.za

M. Grenfell
Department of Earth Sciences, Institute for Water Studies, University of the Western Cape, Bellville 7535, South Africa
e-mail: mgrenfell@uwc.ac.za

S. Tooth
Department of Geography and Earth Sciences, Aberystwyth University, Aberystwyth SY23 3DB, Wales, UK
e-mail: set@aber.ac.uk

A. Mehl
Instituto de Ciencias de la Tierra y Ambientales de La Pampa (INCITAP), CONICET - Universidad Nacional de La Pampa, Uruguay 151, Santa Rosa, La Pampa, Argentina

E. O'Gorman
Discipline of Geography and Planning, Macquarie School of Social Sciences, Macquarie University, North Ryde, NSW 2109, Australia

T. Ralph
School of Natural Sciences, Macquarie University, North Ryde, NSW 2109, Australia

W. Ellery
Department of Geography, Rhodes University, Makhanda, South Africa

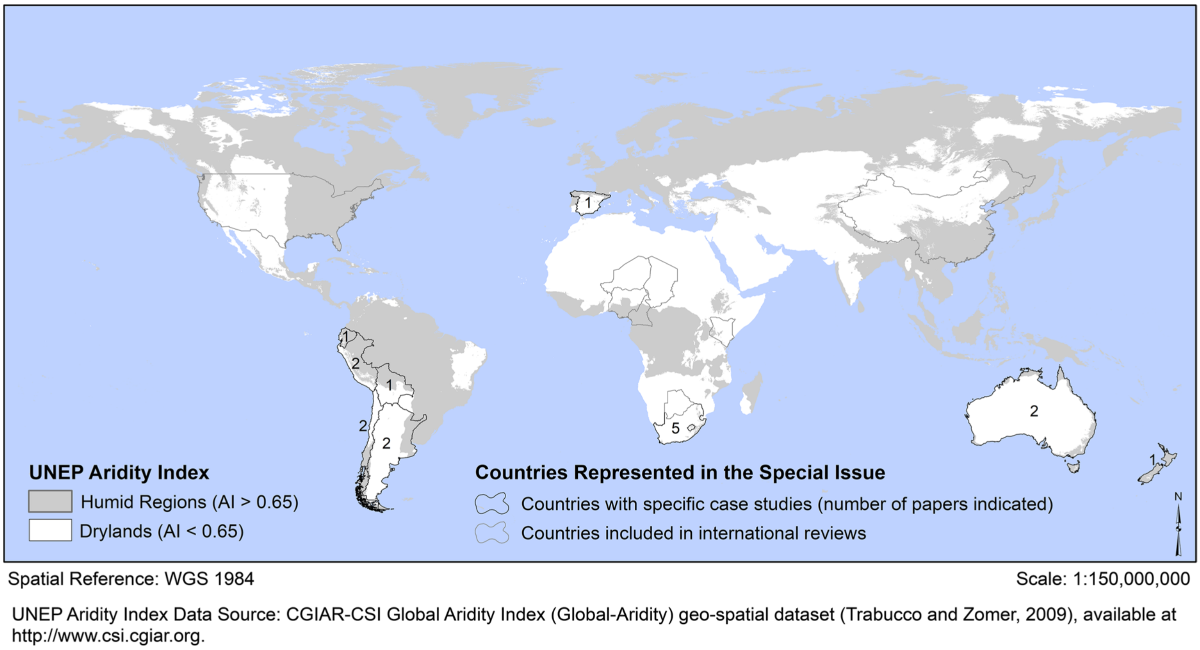


Fig. 1 Geographical scope of original research articles included in this Special Issue in relation to the global extent of drylands (categorised according to the UNEP Aridity Index 1997). Numerals indicate the number of articles within the Special Issue for different countries (specific case studies only; some countries may also be included in international reviews)

that support WiDs ecosystems (Rebelo et al. 2010). This tension is compounded by extreme climatic variability, strong seasonality and annual rainfall deficits, making some WiDs potentially vulnerable to indirect anthropogenic stressors (e.g., climate change) and more direct anthropogenic impacts (e.g., agriculture, mining, and water/sediment regime modification).

While Scoones (1991) appears to have first coined the term 'wetlands in drylands' in an academic publication, Williams (1999) established their significance by drawing attention to a suite of wetland ecosystems that had been overlooked historically. In particular, he suggested that WiDs are much more diverse in their characteristics than wetlands in humid regions (Williams 1998), as they vary widely in terms of their chemistry (fresh or saline), hydroperiod (from permanent, to temporary, to episodic), origin (fluvial, aeolian, tectonic or volcanic), water depth, and source of water (e.g., groundwater, allogenic fluvial). These variations drive the occurrence of distinct biotic assemblages that are specially adapted (Williams 2000). As such, the historical focus of research in WiDs was on ecology, wherein hydrology was considered to be the primary driver of ecosystem processes and dynamics. The traditional emphasis on ecology, moderated by hydrology, continues today. A recent review by Parra et al. (2021) concluded that the main threats to temporary wetlands (their terminology) were those that affected water quality and quantity. By contrast, the impact of changing sediment dispersal patterns and geomorphic processes on the characteristics of WiDs has received less attention.

Nevertheless, researchers in the southern hemisphere have increasingly focused on the role of geomorphology in the formation and dynamics of WiDs over decadal to multimillennial timescales. Tooth and McCarthy (2007) and Ellery et al. (2009) synthesised an emerging geomorphic knowledge base and highlighted the key physical and chemical controls that distinguished WiDs from their better studied humid-region counterparts. Tooth and McCarthy (2007) proposed five distinct characteristics common to many WiDs: (1) they are prone to more frequent and/or longer periods of desiccation; (2) many have channels that decrease in size and even disappear downstream; (3) evapotranspiration processes result in higher levels of chemical sedimentation; (4) as they are often nested within fire-prone landscapes, they may be exposed to more frequent fires that reduce the potential for thick organic accumulations and promote aeolian deflation; and (5) many have long timescales of development that may extend to before the last glacial maximum. Clearly, for most WiDs, geomorphology is as important in driving ecosystem processes as is climate (Tooth et al. 2015b; Tooth 2018; Lisenby et al. 2019). In recognition of the importance of geomorphic processes to the successful scientific analysis, management and restoration of WiDs, a wetland classification system for South African palustrine wetlands based on geomorphic mode of formation was subsequently developed (Grenfell et al. 2019). Building on earlier work (e.g., Cowardin and Golet 1995; Ollis et al. 2015), this classification includes those WiDs associated with fluvial processes (i.e., along drainage lines), aeolian processes (due to deflation), colluvial processes (on hillslope seepage zones) and geochemical processes (dissolution and/or cycles of wetting and drying).

Development of the wetlands in drylands research network

The Wetlands in Drylands (WiDs) Research Network was established at an inaugural meeting held in November 2014 near Parys, South Africa. The network is a collaborative international initiative with the goal of promoting holistic analysis and sustainable management of WiDs and their surrounding hydrological, geomorphological, ecological, and social landscapes, in order to emphasise the benefits that these systems bring to humanity (Wetlands in Drylands Research Network 2014). Following the Parys meeting, in September 2016 the network coordinated a special session at the 10th INTECOL International Wetlands Conference in Changshu, China, entitled 'wetlands in drylands: enigmatic but neglected ecosystems valuable for human wellbeing'. In July 2017, a second network meeting was held at Macquarie University, Australia, with the theme of 'Dynamic Landscapes', from which the title of this Special Issue takes inspiration (Ralph 2017). Network members have since contributed to numerous dryland river and wetland-relevant workshops and conference symposia in Jordan, South Africa, the UK and Argentina, expanding the geographical reach of network membership in the process. Following the cancellation of a planned meeting in 2020 owing to the COVID-19 pandemic, this Special Issue was conceived to continue the network's activities and invite further collaboration. The Special Issue aimed to: (1) consolidate, extend and challenge current global scientific understanding of the hydrogeomorphology, biogeomorphology, biogeochemistry, ecology, and social-ecology of WiDs; (2) illustrate the linkages between biophysical, social, and cultural processes and practices, and their implications for ecosystem service provision; and (3) promote the system-scale management and restoration of WiDs ecosystems and their linked social-ecological/cultural systems, in order to maximise the services they provide to dryland societies. In this editorial, we provide an overview and some additional context for the articles included in the Special Issue. We outline the geographical and topical scope of the articles, synthesise the findings in relation to a variety of emergent research themes, and revisit the distinctive biophysical characteristics of WiDS. We conclude by identifying future prospects for WiDs research and management.

Overview and scope of articles in the Special Issue

This Special Issue comprises original research from South Africa, Australia, Argentina, Peru, Chile, Spain, Ecuador, Bolivia and New Zealand (the latter being a dominantly humid environment, included in Moggridge et al. 2022 for comparative purposes only) (Table 1; Fig. 1). Two international reviews of literature extend this coverage to other parts of Africa (Botswana, Chad, Cameroon, Nigeria, Niger, and Kenya) as well as China and the United States (Table 1; Fig. 1). The articles illustrate the wide geographical and thematic scope of research into WiDs, but there is clear under-representation of the Middle East, dryland Asia and dryland Europe, while large areas of dryland Africa and dryland central and North America are superficially represented.

Eleven topical areas were generalised from the 13 published articles, collectively covering a wide range of disciplines. Each article typically incorporates three or four of the topics (Table 1), showcasing the interdisciplinary nature of WiDs research. As might be expected, hydrology is a consideration in 69% of the articles, while fauna and/or flora are major research foci in 77% (Fig. 2). Demonstrating a focus on applied rather than just pure science, 77%

Table 1 Overview of the 13 articles included in this Special Issue

No.	Title	Authors	Country of study	Research topics										
				Geomorphology	Hydrology	Geochemistry	Fauna	Flora	Management/Human Impacts/Ecosystem services/Inventory	Nutrient recycling	Soil	Traditional knowledge	Geospatial modelling	Climate change
1	Analysis and conceptual geospatial modelling of the intermediary role of wetlands in drylands in post-fire material flux dynamics, Silvermine River catchment, Cape Town	Grenfell et al.	South Africa	x	x			x	x		x		x	
2	Holocene evolution of a floodplain wetland in the dryland piedmont of central-west Argentina	Mehl et al.	Argentina	x	x				x					x
3	Chemical sedimentation as a driver of habitat diversity in dryland wetlands	Humphries & McCarthy	International review	x	x	x	x				x			
4	The physical, chemical, mineralogical, and hydrological properties of three different wetland types in the Kruger National Park	van Huyssteen & Johnson	South Africa	x	x			x		x	x			

Table 1 (continued)

No.	Title	Authors	Country of study	Research topics										
				Geo-mor-phology	Hydrology	Geochem-istry	Fauna	Flora	Manage-ment/Human Impacts/Ecosystem services/Inventory	Nutrient recycling	Soil	Traditional knowledge	Geospatial modelling	Climate change
5	Changes in soil properties across a hydrological gradient in saladas from northeast Spain: implications for soil carbon stocks, CO_2 efflux and microbial communities in a warming world	Thomas et al.	Spain	x	x	x	x	x	x	x	x			x
6	Contextualising sediment trapping and phosphorus removal ecosystem services: a critical review of the influence of spatial and temporal variability in geomorphic processes in alluvial wetlands in drylands	Wiener et al.	International review	x	x	x			x	x	x			
7	Community structure and phenology of the intermittent treed swamps of the Paroo, semi-arid inland NSW, Australia	Timms	Australia		x		x							

Table 1 (continued)

No.	Title	Authors	Country of study	Research topics										
				Geo-morphology	Hydrology	Geochem-istry	Fauna	Flora	Manage-ment/Human Impacts/ Ecosystem services/ Inventory	Nutrient recycling	Soil	Traditional knowledge	Geospatial modelling	Climate change
8	Vegetation patterns in wetlands dominated by the ecosystem engineer Palmiet (*Prionium serratum*)	Rebelo et al.	South Africa		x			x	x					
9	Egg banks in dryland wetlands provide information on the diversity and vulnerability of branchiopod communities along a longitudinal aridity gradient	Meyer-Milne et al.	South Africa				x		x					
10	The arid Andean arid plateau waterscapes and the lithium triangle: flamingos as flagships for conservation of high-altitude wetlands under pressure from mining development	Marconi et al.	Peru, Argentina, Bolivia & Chile		x	x	x	x	x					

Table 1 (continued)

No.	Title	Authors	Country of study	Research topics										
				Geo-mor-phology	Hydrology	Geochem-istry	Fauna	Flora	Manage-ment/Human Impacts/ Ecosystem services/ Inventory	Nutrient recycling	Soil	Traditional knowledge	Geospatial modelling	Climate change
11	Indigenous research method-ologies in water management: Learning from Australia and New Zealand for application on Kamilaroi Country	Moggridge et al.	Australia & New Zealand						x			x		
12	Wetlands of the South America Pacific Coast: A bibliometric analysis	Rivera et al.	Ecuador, Peru & Chile						x					
13	Predicting wetland occurrence in the arid to semi-arid interior of the Western Cape, South Africa, for improved mapping and management	Kotze et al.	South Africa						x				x	

of the articles consider human impacts, implications for management, ecosystem services delivery and/or inventory (Fig. 2). Studies of wetland soils, geochemistry and geomorphology are moderately represented (38%, 31% and 46% respectively), while research that considers nutrient cycling or that uses geospatial modelling approaches is limited (Table 1; Fig. 2). Despite many WiDs being located within regions that are likely to experience lower and/or more variable annual precipitation due to future climate change, only two studies (Thomas et al. 2022; Mehl et al. 2022) specifically highlighted climate change as a research theme (Table 1; Fig. 2). Furthermore, despite the importance of timescales for processes and rates of change, the primary use of geochronology is limited to a single paper (Mehl et al. 2022). Only one article (Moggridge et al. 2022) considers the potential benefits of incorporating Indigenous knowledge in wetlands management (Table 1; Fig. 2), noting that protecting water resources in dryland environments has been critical for the survival of Indigenous peoples for millennia.

Although none of the studies in the Special Issue directly evaluate a particular wetland restoration project, several of the studies address the building blocks of ecosystem service provision in WiDs; for example, carbon storage in Thomas et al. (2022), regulation of erosion and sedimentation in Grenfell et al. (2022) and Wiener et al. (2022), and regulation of water and sediment chemistry and biodiversity in Humphries and McCarthy (2022). Potentially, therefore, these types of studies could contribute to the design of restoration interventions for ecosystem service provision. Studies of wetland edaphic conditions (Van Huyssteen and Johnson 2022), vegetation succession (Rebelo et al. 2022) and the use of biota as indicators of ecosystem processes and stressors (Marconi et al. 2022; Meyer-Milne et al. 2022; Timms 2022) are equally valuable in ensuring that restoration strategies address drivers of change and promote natural recovery in abiotic-biotic linkages. The inclusion of traditional ecological knowledge (Moggridge et al. 2022) is viewed as a critical practical strategy for strengthening the effectiveness of ecological restoration and promulgating a global restorative culture to achieve the ideals of the United Nations "Decade on Ecosystem Restoration" (2021–2030) (Aronson et al. 2020).

Synthesis of articles and emergent research themes

The 11 topical areas outlined in Table 1; Fig. 2 can be synthesised into overarching, emergent research themes, each of which complements and significantly extends previously published wetlands research. In the following sections, we outline four main emergent themes, dovetailing some of the key findings from the articles in the Special Issue with earlier research findings.

Emergent theme 1: recognising alternate states in wetlands in drylands

High climatic variability is a feature of most drylands, and as a result, climatically-induced disturbances (e.g., extreme floods or droughts, or fires driven by distinct seasonality) are an important component of the natural dynamics of geomorphic and/or ecological processes in WiDs. These disturbances and dynamics have the potential to shift wetlands between alternate ecosystem states. In some non-perennial rivers, for example, wetlands (e.g., isolated pools, linear reedbeds) appear within channels between system-integrating flood flows, resulting in a dichotomous switch between 'river' and 'wetland' driven by precipitation events (e.g., Bunn et al. 2006; Heffernan 2008, Stromberg et al. 2009; Grenfell et al. 2020). Leigh et al. (2010) suggest that this flow variability is essential in maintaining dryland river and wetland habitats and biodiversity. Similarly, some valley-bottom WiDs (also referred to as valley fill swamps, valley mire fens or ciénegas in literature) have been characterised by phases of incision, whether induced by crossing of an intrinsic geomorphic threshold, or by crossing of an extrinsic geomorphic threshold triggered by anthropogenic or climatic stressors (e.g., Fryirs and Brierley 1998; Tooth et al. 2014; Pulley et al. 2018; Grenfell et al. 2019, 2020). These types of systems oscillate spatio-temporally between palustrine valley-fill wetlands and incised gully networks over centennial to millennial timescales. Similarly, the Argentinean Andean piedmont exhibits extensive floodplain wetlands in distributary fluvial systems showing spatio-temporal adjustments to climatic and anthropogenic stressors (Mehl et al. 2022). As noted by Moggridge et al. (2022) in places like Australia, Indigenous people's knowledge of these dynamics has been passed between generations for 1000s of years. Indigenous people should be central in WiDs management, and management structures therefore need to be culturally appropriate (Moggridge et al. 2022).

The distinctive and variable hydrological and geomorphic conditions of these types of WiDs have significant implications for successional processes which influence the diversity in fauna and flora. Traditional succession theory, which implies a directional, often linear, change in community structure, is unlikely to apply in WiDs that are subjected to severe disturbance (Rebelo et al. 2022). In considering vegetation dynamics in palmiet wetlands in South Rebelo et al. (2022) found that vegetation patchiness, and thus community diversity, appears to be driven by disturbance (fire and/or incision). As such, severe disturbances which cause switching between alternative states leave a 'mark' that influences future species assemblages, and disturbances are therefore integral to the long-term ecological structure of such wetlands.

The implications of alternate states for geomorphic processes and floral and faunal ecology translate through to ecosystem services, as certain wetland types may be better at delivering some specific ecosystem services than others. As Wiener et al. (2022) indicate, geomorphic processes within floodplain and valley-bottom WiDs may preclude the long-term (i.e., > 50,000 years) storage of contaminants or nutrients attached to sediment. In floodplain wetlands, sediment is commonly cycled and exchanged between channel and floodplain through a combination of meander migration or floodplain stripping processes operating over centennial to multimillennial timescales (e.g. Keen-Zebert et al. 2013), whereas in valley-bottom wetlands, sediment may be eroded and exported during the transition to an incisional phase (e.g., sensu Patton and Schumm 1981).

Emergent theme 2: implications of climate change for biodiversity in wetlands in drylands

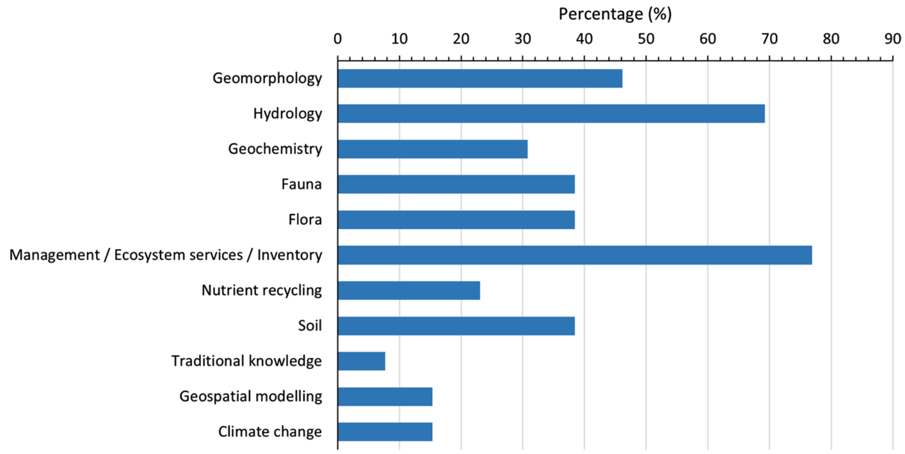
WiDs have been shown to have extremely high faunal diversity that may exceed that of more permanent wetlands. Williams (2000) attributes this higher diversity to the fact that while some of the fauna in WiDs also occurs in permanent wetlands, many species are uniquely adapted to more temporary environments and may therefore be restricted to these environments. Eggs and seeds stored in wetland sediment, for instance, have the potential to provide resilience to climatic variability as they may remain viable following extended periods of dormancy during drought conditions (Parra et al. 2021). However, the studies of ecosystems published in this Special Issue highlight that there may be limits to these adaptations and the associated resilience, and instead draw attention to the vulnerability of wetland biodiversity to increasing aridity.

For instance, in their study of branchiopod communities in temporary wetlands of South Africa, Meyer-Milne et al. (2022) found that fewer branchiopod eggs were stored in wetland soil sub-surface layers as aridity increased. This suggests that although egg and seed stores might provide an opportunity for species to survive droughts, sustained increases in aridity as a consequence of climate change may exceed species resilience. Furthermore, it was found that egg abundance decreased with alkalinity, a property that may also be influenced by increasing aridity.

Similarly, Timms (2022) found that invertebrate diversity in intermittent treed swamps of Australia was lower than that of other WiDs in the region. This disparity was accredited to the shorter hydroperiod and simpler geomorphology of the treed swamps which reduced species replacement during the periods in which branchiopods and insects were dominant. The overall effect, as in the study by Meyer-Milne et al. (2022), is a reduction in biodiversity with aridity. In extreme cases of prolonged drought, it is possible that these systems may even become terrestrialised (cf., Sandi et al. 2019), with permanent loss of wetlands.

Marconi et al. (2022) consider the implications of climate change from a completely different perspective in their account of high-altitude wetlands located within the Andean plateau. Like most WiDs, the region is characterised by a negative water budget due to high rates of evapotranspiration and consequently inputs of fossil groundwater are important in sustaining diverse wetland ecosystems. However, the region is also characterised by rich deposits of base metals, many of which are required for the world's batteries. These deposits include ~ 30% of the world's lithium. Lithium carbonate is extracted by evaporating brine in open pools, followed by processing of the harvested salts. The process requires large volumes of fresh water from ground and surface sources, exacerbating

Fig. 2 Percentage of articles included within this Special Issue in relation to 11 generalised research topics. Note that most of the articles cover more than one topic



regional water scarcity, and placing further water stress on freshwater ecosystems and communities.

Emergent theme 3: implications of seasonality and climatic variability for supporting and regulating ecosystem services in wetlands in drylands

Water and sediment fluxes in WiDs are moulded by the prevailing climatic conditions. In their global review of wetland accretion processes, Wiener et al. (2022) found that although there is wide overall variability in vertical accretion rates for floodplain systems, accretion rates in WiDs were typically lower due to greater seasonality and thus greater inter-annual variability in sediment-delivering flows. In valley-bottom wetland systems, organic accretion rates in permanent, humid-region wetlands typically outstripped clastic sedimentation rates of seasonal wetlands. In addition to the potential impact of climate on sediment accumulation rates, Wiener et al. (2022) postulate that seasonal cycles of desiccation of sediments in WiDs will likely strengthen phosphorus retention due to oxidation. Further, process dynamics in WiDs are equally as vulnerable as humid region wetlands to human-induced changes in riverine sediment flux, that may cause either siltation (e.g., Wolanski et al. 2001, Gell et al. 2009) or erosion (Fryirs and Brierley 1998) of wetlands downstream.

WiDs may also play a pivotal role in buffering the impact of climatic variability on geomorphic and hydrological processes. Many WiDs are nested within fire-prone landscapes (Kotze 2013; Grenfell et al. 2022) consider how wetlands mediate runoff and sediment fluxes in a post-fire landscape. Following a major fire in a South African catchment, they found that wetland soils had a much lower soil-water repellency compared to other areas of the landscape. This was attributed to the mitigating effect of increased soil moisture. In addition, wetland vegetation responded rapidly to post-fire rainfall, resulting in a 'green flush' that intercepted and reduced early wet season runoff and erosion. Through a combination of reduced hydrophobicity and increased potential for interception, some WiDs thus are able to mediate sediment fluxes in fire-prone landscapes.

In a review of chemical sedimentation processes in WiDs, Humphries and McCarthy (2022) show that wetland vegetation can localise the accumulation of salts within soils through focused evapotranspiration processes, ensuring that even in areas prone to high evaporative losses, surface water may remain fresh. In addition to this regulating service, Humphries and McCarthy (2022) demonstrate the importance of chemical sedimentation in driving topographic and thus habitat diversity, providing another example of how physical processes that mediate wetland topographic structure can influence ecosystem development.

In terms of carbon storage in WiDs, Thomas et al. (2022) found that the relationship between rainfall, relative aridity and carbon storage in saline inland wetlands ('saladas') in Spain was nuanced. While a near-permanent hydroperiod supports the generation of organic carbon, in less frequently inundated saladas inorganic carbon production and storage is promoted due to processes of evapotranspiration that concentrate carbonate ions. As such, they found that both the wettest *and* the driest saladas were potentially important carbon sinks. In contrast, saladas that may be considered 'intermediate' in terms of hydroperiod (not wet enough for generation of substantial organic material but not dry enough for substantial chemical sedimentation) are less likely to be important sinks and tend to generate higher CO_2 emissions. However, predicting the overall effect of climate change on carbon storage across the full gradient of salada hydroperiods is not simple. Some saladas may become drier (and potentially better at accumulating inorganic carbon), while others may move into the intermediate category (and thus become higher CO_2 emitters), while others may become wetter (and potentially accumulate more organic carbon). The potential for organic sediment accumulation under wetter conditions may be constrained by geology and the resulting salinity of input water, as shown by Van Huyssteen and Johnson (2022) in their comparison of three WiDs situated in the Kruger National Park of South Africa.

Emergent theme 4: employing different scales of investigation in wetlands in drylands to provide both 'big picture' and 'invisible process' insights

Broad-scale analyses of wetland distribution are invaluable to WiDs management at regional to national scales and are becoming increasingly viable in an age of big data analytics. Kotze et al. (2022) illustrate the potential; working across an aridity gradient in the Western Cape Province of South Africa, they identified differences in the proportional area of wetland and in the representation of different wetland hydrogeomorphic types. Spatial probability modelling was then used to advance understanding of the key attributes of different wetland types that influence wetland vulnerability to climatic or anthropogenic stressors.

The bibliometric analysis of Rivera et al. (2022) similarly illustrates the value of broad-scale analysis (in both geographical and topical terms) of a regional wetland knowledge base but also highlights a need for more research in WiDs into microscopic organisms, and pathology and public health (their bibliometric themes). This need may apply more widely, with Thomas et al. (2022) also highlighting the importance of further research that is aimed at understanding linkages between hydrogeomorphology and soil carbon stocks, CO_2 efflux, and microbial communities. If pursued, such research will help to facilitate full-system science for WiDs ecosystem management. With the exception of some previous work on bacterial biocrusts (e.g., Thomas et al. 2014), the focus of most WiDs research has tended to be on more readily observable ecological features but an increasing emphasis on 'invisible' microbial and other micro-scale ecological processes will help contribute to wider trends in biogeomorphology, where the link between life and landscape is gaining greater recognition (e.g., Viles 2012).

Revisiting the distinct biophysical characteristics of wetlands in drylands

The publication of this Special Issue provides an opportunity to revisit the five distinct biophysical characteristics of WiDs proposed by Tooth and McCarthy (2007). Doing so allows us to consider the progress that has been made in furthering our understanding of biophysical processes in WiDs over the last 15–20 years, contemplate how this translates into improved knowledge about WiDs ecological dynamics and ecosystem service delivery, and identify where some of the key knowledge gaps remain.

More frequent and/or longer periods of desiccation

As highlighted in the foregoing sections, this is one of the defining characteristics of WiDs and ultimately is a driver of many of the other characteristics. For instance, seasonal desiccation and/or more prolonged periods of no river inflow in some WiDs is associated with chemical sedimentation processes (e.g., McCarthy and Ellery 1995; Humphries and McCarthy 2022) and more frequent fires (e.g., Staver et al. 2011 demonstrate importance of climatic seasonality in determining fire regime and vegetation type). Desiccation also has implications for nutrient assimilation (e.g., Wiener et al. 2022), carbon storage or release (Thomas et al. 2022), and sediment availability in the surrounding landscape (McCarthy et al. 2011). The special role of groundwater discharge in WiDs needs further consideration, as this can keep some types of wetlands moist when surface inputs are at a minimum (Grenfell et al. 2022; Thomas et al. 2022; van Huyssteen and Johnson 2022).

Channels that commonly decrease in size and even disappear downstream

Not all WiDs are connected to river channels (e.g., pans and playas—see Thomas et al. 2022) but many of the moderate size to larger WiDs are associated with river inflows. The phenomenon of downstream channel size reduction in many dryland rivers feeding wetlands has been well documented in multiple studies (e.g., Jurmu and Andrle 1997; Tooth et al. 2002, 2014; Ralph and Hesse 2010: Larkin et al. 2017, 2020a; Li et al. 2019). Most recently, this phenomenon was used as one of the primary discriminants of fluvial styles in Australia, and to associate fluvial styles with specific aridity zones, including many dryland rivers with floodplain and in-channel wetlands (Larkin et al. 2020b). This follows earlier observations that the transport-limited conditions inherent to many dryland rivers (Milliman and Farnsworth 2011) is sometimes expressed in geomorphic features such as 'floodouts' (Tooth 1999). A distinct 'floodout zone' (often associated with WiDs development) was included in the idealised longitudinal zonation depicted for non-perennial rivers by Tooth and Nanson (2011) and Jaeger et al. (2017), with rivers transitioning downstream from a production zone, through a transfer zone and to a deposition zone. In detail, however, non-perennial river systems are seldom characterised by this steady sequential transition or ecology-based depictions of the river continuum, but instead tend to be characterised by longitudinal patchiness (Thorp et al. 2006; Burchstead et al. 2014). For example, variations in lithology or tributary inputs that control changes in valley width and slope are often instrumental in driving abrupt transitions between zones that run counter to ideas of a steady downstream transition or a continuum (e.g., McCarthy et al. 2011; Keen-Zebert et al. 2013). While the process implications of spatially and temporally episodic or intermittent material flux transfers through wetlands at catchment scale is under consideration (e.g., Leigh et al. 2010; Von Schiller et al. 2017), evaluation of the relative importance of intrinsic and extrinsic controls on channel narrowing and floodout formation in intermediate catchment locations remains a challenge that could be addressed through morphodynamic modelling.

Higher levels of chemical sedimentation

As demonstrated by Humphries and McCarthy's (2022) review, chemical and biogeochemical sedimentation processes have been documented in numerous WiDs. Nevertheless, more information is needed about the relationship between these sedimentation processes and freshwater availability on a case study basis, as human impacts have the potential to disrupt processes that mediate both water quality and habitat diversity. Similarly, the work by Thomas et al. (2022) provides a useful starting point for understanding how the biogeochemical processes relevant to inorganic and organic carbon storage vary across an aridity gradient, but also highlights the importance of determining the potential climatic thresholds between net C retention or net C emission, in order to make projections relating to future climate changes. The same requirement applies in terms of wetting and drying cycles in enhancing phosphate assimilation (e.g., Wiener et al. 2022). Lastly, the role of chemical sedimentation and weathering processes in the formation of geochemical depressions (*sensu* Grenfell et al. 2019) requires further investigation. These understudied WiDs include subsidence depression wetlands (typically formed by saturation of underlying bedrock, and subsidence associated with hydrolysis, as described by Edwards et al. 2016) and redox depression wetlands (where repeated wetting and drying cycles simultaneously causes dissolution in the centre of the pan, while building relief around the perimeter.

More frequent fires that reduce the potential for thick organic accumulations and promote aeolian activity

The impact of fires on WiDs is understudied in comparison to the other listed characteristics. In the most arid regions of the globe, the lack of vegetation limits the build-up of fuel and so impedes fire frequency. In the grassland biome of South Africa, however, fires are thought to have recurred every 5 to 8 years under natural conditions (Gordjin et al. 2018), while in fynbos/chaparral/Mediterranean regions it may be more periodic (e.g., 8–16 years for fynbos regions of South Africa, Kraaij and van Wilgen 2014). In wetlands in these dryland environments, fire is an important moderator of nutrient cycling processes (Kotze 2013). However, the main impact of fire may not be within the wetland itself, but rather across the surrounding catchment where vegetation-free hillslopes in the post-fire phase increase run-off (reduced interception, increased soil hydrophobicity), sediment availability and sediment transport (Grenfell et al. 2022). The impact of these changes cascade through the landscape, ultimately impacting upon geomorphic and ecological processes within the wetland itself. The full impact of individual fires and/or changing fire regimes on geomorphic process rates and dynamics within WiDs have not been adequately explored. This is a fundamental gap as fire regimes are influenced by anthropogenic activities which can suppress or enhance fire frequency and intensity, and thus have the potential to modify WiDs.

Since the publication of Tooth and McCarthy (2007), the link between fires in WiDs and subsequent aeolian erosion has not been supported by case studies in the literature, which suggests that this process may be less important than originally envisaged. Nevertheless, in seasonally or ephemerally inundated depressions characterised by high salinity and therefore little or no vegetation cover (e.g., pans, playas and some desert lakes), aeolian deflation remains an important geomorphic process in the maintenance and/or ongoing development of the depressions (e.g., Thomas et al. 2022) while other types of fluvial-aeolian interactions can lead to a wide array of floodplain wetland forms (e.g., Mehl et al. 2022).

Longer timescales of development that may extend far back into the Pleistocene

Developing a fuller understanding of spatial variability in the timescales of WiDs development has been hampered by the cost of geochronology, especially in the Global South. Nevertheless, a number of case studies of floodplain WiDs now exist, revealing how sediment may be slowly recycled through meander migration over multimillenia, with the initiation of many WiDs pre-dating the last glacial maximum (e.g., Tooth et al. 2007; Keen-Zebert et al. 2013). For aeolian or geochemically-derived depression wetlands, timescales of development may be even longer, as evidenced by pans located on the ancient land surfaces (e.g., the 'African Erosion Surface' in South Africa; Grenfell et al. 2019). However, there is a need to consider wetland age within a context defined by processes, as some dryland wetlands may be much younger. For example, Mehl et al. (2022) document a variety of fluvial environments, including floodplain wetlands, all younger than 4500 years BP. Furthermore, Wiener at al. (2022) assembled published maximum basal ages for 18 valley-bottom type wetlands, where the mean age was 11,330 years BP. This age is exaggerated by a single outlier, however, so when omitted the mean basal age was substantially younger at 6299 years BP. In these wetlands, ongoing but pulsed sediment accumulation results in oversteepening of the longitudinal profile and exceedance of a geomorphic threshold (Ellery et al. 2009). As such, wetland sedimentation is more frequently disrupted and 'reset' than is typical in some humid-region floodplain wetlands which may gradually adjust to more slowly varied sediment and water inputs. The jerky downstream movement of sediment in valley-bottom wetlands may well be an expression of climatic variability (e.g., Grenfell et al. 2014).

Conclusions

This editorial accompanies the Special Issue entitled 'wetlands in drylands: diverse perspectives for dynamic landscapes' and has highlighted the linkages between diverse disciplines (i.e., hydrogeomorphology, biogeomorphology, biogeochemistry, ecology, and social-ecology) that are essential for successful research into WiDs. Furthermore, our overview of the articles in the Special Issue, and their positioning against the wider literature on wetlands, has helped to identify the type of research that could be used to promote the system-scale management, wise-use, and restoration of WiDs. The interdisciplinary nature of the research presented in the articles, much of which has practical implications for management and restoration approaches, is indicative of the healthy state of research in WiDs. Nevertheless, our overview also reveals geographical imbalance in global WiDs research as well as some underrepresented study approaches and under-researched topics that will need to be addressed in the future. Perhaps the key to progressing WiDs research and management will be to continue to grow the community of wetland scientists, practitioners, policy makers, and volunteer enthusiasts. Particularly in the context of the United Nations "Decade on Ecosystem Restoration" (2021–2030), an increasing emphasis on citizen science approaches (e.g., Gann et al. 2019) could provide one way of increasing local community engagement with, and longer-term investment in, conservation and restoration efforts for degraded WiDs. The Wetlands in Drylands Research Network and the annual South African Wetlands Indaba provide examples of the sorts of activities that can help catalyse growth of these much needed interdisciplinary, holistic collaborations that mesh a diversity of perspectives, including those associated with traditional ecological knowledge.

Acknowledgements We give our special thanks to Professor Eric Wolanski for his assistance in bringing together this Special Issue. We also express our gratitude to all the reviewers who assisted with the individual articles in the Special Issue.

Author contributions SG, MG and ST wrote the manuscript text. MG prepared Figure 1, SGprepared Figure 2 and Table 1. Other authors reviewed and commented on themanuscript. All authors served as Guest Associate editors for the specialissue.

Funding There are no funding sources to declare.

Declarations

Conflict of interest The authors declare no competing interest.

References

Aronson J, Goodwin N, Orlando L, Eisenberg C, Cross AT (2020) A world of possibilities: six restoration strategies to support the United Nation's Decade on Ecosystem Restoration. Restor Ecol 28: 730–736. https://doi.org/10.1111/rec.13170

Bunn SE, Thoms MC, Hamilton SK, Capon SJ (2006). Flow variability in dryland rivers: boom, bust and the bits in between. River Res Appl 22: 179–186

Burchsted D, Daniels M, Wohl EE (2014) Introduction to the special issue on discontinuity of fluvial systems. Geomorphol 205: 1–4

Cowardin LM, Golet, FC (1995) US fish and wildlife service 1979 wetland classification: a review. Vegetatio 118: 139–152

Edwards RJ, Ellery WN, Dunlevey J (2016) The role of the in situ weathering of dolerite on the formation of a peatland: The origin and evolution of Dartmoor Vlei in the KwaZulu-Natal Midlands, South Africa. Catena 143: 232–243

Ellery W, Grenfell M, Grenfell S, Kotze D, McCarthy TS, Tooth S, Grundling PL, Beckedahl H, Le Maitre D, Ramsay L (2009) WET-Origins: controls on the distribution and dynamics of wetlands in South Africa. Water Research Commission Report TT334/09, Pretoria

Fryirs K, Brierley G (1998) The character and age structure of valley fills in upper Wolumla Creek catchment, south coast, New South Wales, Australia. Earth Surf Proc Landf 23(3): 271–287

Gann GD, McDonald T, Walder B, Aronson J, Nelson CR, Jonson J, Hallett JG, Eisenberg C, Guariguata MR, Liu J, Hua F, Echeverría C, Gonzales E, Shaw N, Decleer K, Dixon KW (2019) International principles and standards for the practice of ecological restoration. Second edition. Restor Ecol 27:S1–S46

Gell P, Fluin J, Tibby J, Hancock G, Harrison J, Zawadzki A, Haynes D, Khanum S, Little F, Walsh B (2009) Anthropogenic acceleration of sediment accretion in lowland floodplain wetlands, Murray–Darling Basin, Australia. Geomorphology 108(1–2):122–126

Gordijn PJ, Everson TM, O'Connor TG (2018) Resistance of Drakensberg grasslands to compositional change depends on the influence of fire-return interval and grassland structure on richness and spatial turnover. Perspect Plant Ecol Evol Syst 34:26–36

Grenfell SE, Grenfell MC, Rowntree KM, Ellery WN (2014) Fluvial connectivity and climate: a comparison of channel pattern and process in two climatically contrasting fluvial sedimentary systems in South Africa. Geomorphol 205:142–154

Grenfell S, Grenfell M, Ellery W, Job N, Walters D (2019) A genetic geomorphic classification system for southern African palustrine wetlands: global implications for the management of wetlands in drylands. Front Environ Sci 7:174

Grenfell SE, Mamphoka MF, Grenfell MC, Job N (2020) Evaluating the potential for natural ecosystem recovery in cut-and-fill wetlands: case study of Pietersielieskloof palmiet wetland, South Africa. Wetlands Ecol Manag 28(6):863–882

Grenfell MC, Abrahams E, Fisher RM (2022) Analysis and conceptual geospatial modelling of the intermediary role of wetlands in drylands in post-fire material flux dynamics, Silvermine River catchment, Cape Town. Wetlands Ecol Manag. https://doi.org/10.1007/s11273-022-09859-3 (this issue)

Heffernan JB (2008) Wetlands as an alternative stable state in desert streams. Ecol 89(5):1261–1271

Humphries M, McCarthy T (2022) Chemical sedimentation as a driver of habitat diversity in dryland wetlands. Wetlands Ecol Manag. https://doi.org/10.1007/s11273-021-09851-3 (this issue)

Jaeger KL, Sutfin NA, Tooth S, Michaelides K, Singer M (2017) Geomorphology and sediment regimes of intermittent rivers and ephemeral streams. In: Datry T, Bonada N, Boulton A (eds) Intermittent rivers and ephemeral streams: ecology and management, 1st edn. Academic Press, London, pp 21–49

Jurmu MC, Andrle R (1997) Morphology of a wetland stream. Environ Manag 21:921–941

Keen-Zebert A, Tooth S, Rodnight H, Duller GAT, Roberts HM, Grenfell M (2013) Late Quaternary floodplain reworking and the preservation of alluvial sedimentary archives in unconfined and confined river valleys in the eastern interior of South Africa. Geomorphol 185:54–66

Kotze DC (2013) The effects of fire on wetland structure and functioning. Afr J Aquat Sci 38(3):237–247

Kotze DC, Rivers-Moore NA, Job N, Grenfell M (2022) Predicting wetland occurrence, main hydrogeomorphic type and vulnerability in the predominantly arid to semi-arid interior of the Western Cape, South Africa. Wetlands Ecol Manag. https://doi.org/10.1007/s11273-022-09882-4 (this issue)

Kraaij T, van Wilgen BW (2014) Drivers, ecology and management of fire in Fynbos. In: Allsop N, Colville JF, Verboom GA (eds) Fynbos: ecology, evolution and conservation of a megadiverse region. Oxford University Press, Oxford, pp 47–72

Larkin ZT, Ralph TJ, Tooth S, McCarthy TS (2017) The interplay between extrinsic and intrinsic controls in determining floodplain wetland characteristics in the South African drylands. Earth Surf Process Landf 42:1092–1109

Larkin ZT, Ralph TJ, Tooth S, Duller GAT (2020a) A shifting 'river of sand': the profound response of Australia's Warrego River to Holocene hydroclimatic change. Geomorphol 370: 107385

Larkin ZT, Ralph TJ, Tooth S, Fryirs KA, Carthey AJR (2020b) Identifying threshold responses of Australian dryland rivers to future hydroclimatic change. Sci Rep 10(1):1–15

Leigh C, Sheldon F, Kingsford RT, Arthington AH (2010) Sequential floods drive 'booms' and wetland persistence in dryland rivers: a synthesis. Marine Freshw Res 61(8):896–908

Li J, Tooth S. Yao G (2019) Cascades of sub-decadal, channel-floodplain changes in low-gradient, non-vegetated reaches near a dryland river terminus: Salar de Uyuni, Bolivia. Earth Surf Process Landf 44:490–506

Lisenby PE, Tooth S, Ralph TJ (2019) Product vs. process? The role of geomorphology in wetland characterization. Sci Total Environ 663:980–991

Marconi P, Arengo F, Clark A (2022) The arid Andean plateau waterscapes and the lithium triangle: flamingos as flagships for conservation of high-altitude wetlands under pressure from mining development. Wetlands Ecol Manag. https://doi.org/10.1007/s11273-022-09872-6 (this issue)

McCarthy TS, Ellery WN (1995) Sedimentation on the distal reaches of the Okavango Fan, Botswana, and its bearing on calcrete and silcrete (ganister) formation. J Sediment Res 65(1a):77–90

McCarthy TS, Tooth S, Jacobs Z, Rowberry MD, Thompson M, Brandt D, Hancox PJ, Marren PM, Woodborne S, Ellery WN (2011) The origin and development of the Nyl River floodplain wetland: trunk-tributary river interactions in a dryland setting. S Afr Geograph J 93:172–190

Mehl AE, Zárate MA, Lorenzo FR (2022) Holocene evolution of a floodplain wetland in the dryland piedmont of central-west Argentina. Wetlands Ecol Manag. https://doi.org/10.1007/s11273-022-09880-6 (this issue)

Meyer-Milne E, Brendonck L, Pinceel T (2022) Egg banks in dryland wetlands provide information on the diversity and vulnerability of branchiopod communities along a longitudinal aridity gradient. Wetlands Ecol Manag. https://doi.org/10.1007/s11273-021-09852-2 (this issue)

Milliman JD, Farnsworth KL (2011) River discharge to the coastal ocean: a global synthesis. Cambridge University Press, Cambridge

Moggridge BJ, Thompson RM, Radoll P (2022) Indigenous research methodologies in water management: learning from Australia and New Zealand for application on Kamilaroi Country. Wetlands Ecol Manag. https://doi.org/10.1007/s11273-022-09866-4 (this issue)

Ollis DJ, Ewart-Smith JL, Day JA, Job NM, Macfarlane DM, Snaddon CD, Sieben EJJ, Dini JA, Mbona N (2015) The development of a classification system for inland aquatic ecosystems in South Africa. Water SA 41:727–745

Parra G, Guerrero F, Armengol J, Brendonck L, Brucet S, Finlayson CM, Gomes-Barbosa L, Grillas P, Jeppesen E, Ortega F, Vega, R (2021) The future of temporary wetlands in drylands under global change. Inland Waters 11(4):445–456

Patton PC, Schumm SA (1981) Ephemeral-stream processes: implications for studies of Quaternary valley fills. Quat Res 15(1):24–43

Pulley S, Ellery WN, Lagesse JV, Schlegel PK, McNamara SJ (2018) Gully erosion as a mechanism for wetland formation: an examination of two contrasting landscapes. Land Degrad Dev 29(6):1756–1767

Ralph TJ (2017) WIDS2017 Dynamic Landscapes: proceedings of the Wetlands in Drylands Research Network Conference. Macquarie University, Sydney, Australia, 24–26 July 2017. ISBN 978-1-74138-454-3 Available at http://wetlandsindrylands.net/wp-content/uploads/2017/04/WIDS2017-Dynamic-Landscapes-Programme-and-Abstracts.pdf

Ralph TJ, Hesse PP (2010) Downstream hydrogeomorphic changes along the Macquarie River, southeastern Australia, leading to channel breakdown and floodplain wetlands. Geomorphol 118:48–64

Rebelo LM, McCartney MP, Finlayson CM (2010) Wetlands of Sub-Saharan Africa: distribution and contribution of agriculture to livelihoods. Wetlands Ecol Manag 18(5):557–572

Rebelo AJ, Sieben E, Meire P, Esler KJ (2022) What drives patchiness in palmiet wetlands? Wetlands Ecol Manag. https://doi.org/10.1007/s11273-021-09853-1 (this issue)

Rivera G, Gonzales S, Aponte H (2022) Wetlands of the South American pacific coast: a bibliometric analysis. Wetlands Ecol Manag. https://doi.org/10.1007/s11273-021-09830-8 (this issue)

Sandi SG, Saco PM, Saintilan N, Wen L, Riccardi G, Kuczera G, Willgoose G, Rodríguez JF (2019) Detecting inundation thresholds for dryland wetland vulnerability. Adv Water Resour 128:168–182

Scoones I (1991) Wetlands in drylands: key resources for agricultural and pastoral production in Africa. Ambio 20 (8):366–371

Silvius MJ, Oneka M, Verhagen A (2000) Wetlands: lifeline for people at the edge. Phys Chem Earth B 25(7–8):645–652

Staver AC, Archibald S, Levin SA (2011) The global extent and determinants of savanna and forest as alternative biome states. Sci 334(6053):230–232

Stromberg JC, Hazelton AF, White MS, White JM, Fischer RA (2009) Ephemeral wetlands along a spatially intermittent river: temporal patterns of vegetation development. Wetlands 29(1):330–342

The Wetlands in Drylands Research Network (2014) Parys Declaration on the importance of Wetlands in Drylands. Available at http://www.wetlandsindrylands.net
Thomas AD, Dougill AJ, Elliott DR, Mairs H (2014) Seasonal differences in soil CO_2 efflux and carbon storage in Ntwetwe Pan, Makgadikgadi Basin, Botswana. Geoderma 219:72–81
Thomas AD, Tooth S, Lan S, Holt T, Saunders I, Tarren H (2022) Soil properties across a hydrological gradient in saladas from northeast Spain: what are the implications for soil carbon stocks, CO2 efflux and microbial communities in a warming world? Wetlands Ecol Manag. https://doi.org/10.1007/s11273-022-09856-6 (this issue)
Thorp JH, Thoms MC, Delong MD (2006) The riverine ecosystem synthesis: biocomplexity in river networks across space and time. River Res Appl 22:123–147
Timms BV (2022) Aquatic invertebrate community structure and phenology of the intermittent treed swamps of the semi-arid Paroo lowlands in Australia. Wetlands Ecol Manag. https://doi.org/10.1007/s11273-021-09846-0 (this issue)
Tooth S (1999) Downstream changes in floodplain character on the Northern Plains of arid central Australia. In: Fluvial sedimentology VI. International Association of Sedimentologists, Special Publication 28, vol 28, pp 93–112
Tooth S (2018) The geomorphology of wetlands in drylands: resilience nonresilience, or…? Geomorphol 305:33–48
Tooth S, McCarthy TS (2007) Wetlands in drylands: geomorphological and sedimentological characteristics, with emphasis on examples from southern Africa. Prog Phys Geogr 31:3–41
Tooth S, Nanson GC (2011) Distinctiveness and diversity of arid zone river systems. In: Thomas DSG (ed) Arid zone geomorphology: process, form and change in drylands, 3rd edn. Wiley-Blackwell, Chichester, pp 269–300
Tooth S, McCarthy TS, Hancox PJ, Brandt D, Buckley K, Nortje E, McQuade S (2002) The geomorphology of the Nyl River and floodplain in the semi-arid Northern Province, South Africa. S Afr Geogr J 84:226–237
Tooth S, Rodnight H, Duller GA, McCarthy TS, Marren PM, Brandt D (2007) Chronology and controls of avulsion along a mixed bedrock-alluvial river. Geol Soc Am Bull 119(3–4):452–461
Tooth S, McCarthy T, Rodnight H, Keen-Zebert A, Rowberry M, Brandt D (2014) Late Holocene development of a major fluvial discontinuity in floodplain wetlands of the Blood River, eastern South Africa. Geomorphology 205:128–141
Tooth S, Grenfell MC, Thomas A, Ellery WN (2015a) Wetlands in Drylands: 'Hotspots' of Ecosystem Services in Marginal Environments. GSDR 2015 Science Brief, United Nations. Available at http://wetlandsindrylands.net.
Tooth S, Ellery W, Grenfell M, Thomas A, Kotze D, Ralph T (2015b) 10 reasons why the geomorphology of wetlands is important. Wetlands in Drylands Research Network. Available at http://wetlandsindrylands.net/wp-content/uploads/2015/10/10-Reasons-Geomorphology-of-Wetlands-NEAR-FINAL-FULL-COLOUR.Pdf
UNEP (1997) World atlas of desertification. United Nations Environment Programme
Van Huyssteen CW, Johnson TL (2022) The physical, chemical, mineralogical, and hydrological properties of three different wetland types in the Kruger National Park. Wetlands Ecol Manag. https://doi.org/10.1007/s11273-022-09883-3 (this issue)
Viles HA (2012) Microbial geomorphology: a neglected link between life and landscape. Geomorphology 157–158:6–16
Von Schiller D, Bernal S, Dahm CN et al (2017) Nutrient and organic matter dynamics in intermittent rivers and ephemeral streams. In: Datry T, Bonada N, Boulton A et al (eds) Intermittent rivers and ephemeral streams: ecology and management, 1st edn. Academic Press, London, pp 135–160
Wiener KD, Schlegel PK, Grenfell SE, van der Waal B (2022) Contextualising sediment trapping and phosphorus removal regulating services: a critical review of the influence of spatial and temporal variability in geomorphic processes in alluvial wetlands in drylands. Wetlands Ecol Manag. https://doi.org/10.1007/s11273-022-09861-9 (this issue)
Williams WD (1998) Dryland wetlands. In: McComb AJ, Davis JA (eds) Wetlands for the future. Gleneagles Publishing, Adelaide, pp 33–47
Williams WD (1999) Conservation of wetlands in drylands: a key global issue. Aquat Conserv Mar Freshw Ecosyst 9(6):517–522
Williams WD (2000) Biodiversity in temporary wetlands of dryland regions. Int Ver Theor Angew Limnol: Verhandlungen 27(1):141–144
Wolanski E, Moore K, Spagnol S, D'adamo N, Pattiaratchi C (2001) Rapid, human-induced siltation of the macro-tidal Ord River Estuary, Western Australia. Estuar Coast Shelf Sci 53(5):717–732.